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PRELIMINARY RESULTS FROM THE EXPERIMENTAL STUDY OF MULTIPATH PR--ETC(U)
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by

V. I. Nurgozhin, A. F. Yakovyets

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78 09 27 074

EDITED TRANSLATION

FTD-ID(RS)T-0409-78 23 March 1978

MICROFICHE NR: FTD-78-C-000409

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English pages: 7

Source: Trudy Sektora Ionosfery, Akademiya Nauk Kazakhskoy SSSR, Vol. 2, 1971, pp. 127-132.

Country of origin: USSR
Translated by: Bernard L. Tauber
Requester: FTD/TQCS

PREPARED BY:

TRANSLATION DIVISION
FOREIGN TECHNOLOGY DIVISION
WP-AFB, OHIO.

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А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

PRELIMINARY RESULTS FROM THE EXPERIMENTAL STUDY OF MULTIPATH PROPAGATION IN THE IONOSPHERE

V. I. Nurgozhin, A. F. Yakovyets

In HF communication over a distance which presumes reflection from the ionosphere, the signal usually arrives at the reception point over various paths. Under certain conditions, in addition to the main beam which is reflected a minimum number of times from the F layer there are beams present which are reflected repeatedly from the F, E, $E_{\text{спор}}$ layers. The difference in the time of signal propagation over the various path leads to a limitation on the maximum possible rate of information transmission over an ionospheric communication channel. By means of simple calculations it is easy to show that it is possible to get rid of beams with large delays to a considerable degree using an increased operating frequency. Theoretical estimates of the dependence of multipath propagation on the operating frequency were made by Bailey [1]. The author introduced the multipath reduction factor which is defined as the minimum frequency expressed in percent relative to the MPCh [maximum usable frequency] where the maximum value of the relative delay between the beams was less than the assigned value.

The result obtained in [1] should evidently be considered as approximate for actual communication channels since the calculations presumed reflections only from the F2 layer which is located at a

constant altitude. In [2], the multipath reduction factor was obtained from experimental data, this time also with consideration of reflections from layers F1 and E. However, this work did not conduct statistical estimates of the relative delay times at different distances from the MPCh, which are extremely important for forecasting the dependence of communication reliability with various rates of data transmission on the frequency being received.

This work presents experimental results from the measurements of multipath propagation on a middle-latitude communication line. The distribution of delay probabilities for frequencies which are at different distances from the MPCh of layer F2 are constructed.

Description of the apparatus. An experimental study of multipath propagation was conducted on a series of 10 frequencies which virtually encompass the entire shortwave band. The carrier frequency on the transmitting end of the route with a length of 3200 km was amplitude-modulated by pulses with a duration of 300 μs. The pulse repetition frequency of 12.5 Hz was synchronized by a highly-stable quartz-crystal oscillator. A block diagram of the receiving apparatus is presented in Fig. 1b. The signal went to an antenna of the center-face dipole type with a suspension height of 30 m. After detection, the signal envelope and the interference went to a resolver which generated illumination pulses for the cathode-ray tube [CRT] with the exceeding of the signal and interference of the threshold level.

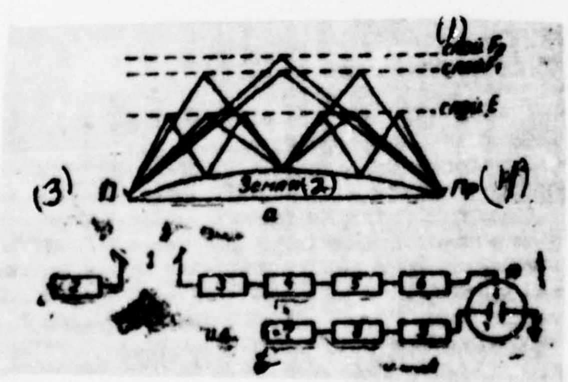

Fig. 1. a - Possible modes for signal propagation in the ionosphere, b - Block diagram of receiving apparatus: 1 - antennas, 2 - transmitter, 3 - receiver, 4 - detector, 5 - cut-off device, 6 - illumination pulse generator, 7 - quartz-crystal oscillator, 8 - divider, 9 - sweep generator, 10 - recorder.

KEY: (1) Layer; (2) Earth; (3) Transmitter; (4) Receiver.

A sawtooth-voltage generator synchronized by a highly-stable quartz-crystal oscillator served as the horizontal sweep of the CRT. Recording of the received signal was accomplished on a motion picture film which was pulled slowly in the direction perpendicular to the line of sweep. Examples of the signal which was received are presented in Fig. 2. Thanks to the synchronization of the CRT's horizontal sweep and the repetition frequency of the arriving pulses, the illumination of the beam when receiving a signal is created at the same distance from the origin of the sweep so that the signal creates horizontal lines on the strip, the distance between which determines the value of the relative delay between the beams. The interference, as a result of the fact that it is not synchronized with the sweep frequency, creates chaotically scattered bright blips on the strip. It is interesting to estimate the minimum ratio of the signal and interference necessary for a given probability of system error. In this system, errors can arise in the following cases: a) if, during the reception of a pulse train the amplitude of the sum of the signal and the interference proves to be less than the threshold level established in the resolver, and b) if during the period of the pause the amplitude of the interference exceeds the threshold level.

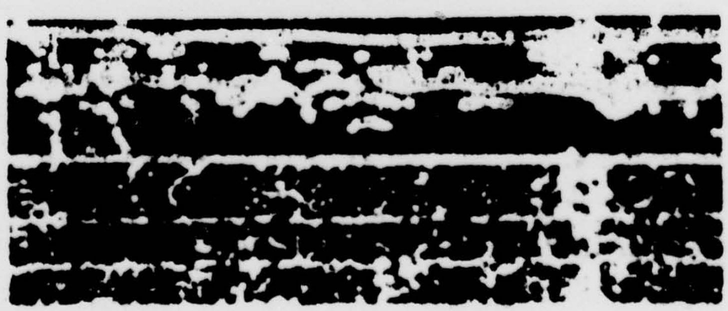

Fig. 2. Samples of the record of a multi-beam signal.

For signal and interference whose amplitudes are distributed in accordance with the Rayleigh law in [3], the probability of errors has been calculated for different $\overline{h^2}=\frac{\sigma_c^2}{\sigma_n^2}$. Here σ_c^2 is the

mean signal power and $\sigma_{п}^{2}$ is the mean noise power. Let us assign an error probability equal to 5%; then $\sqrt{h^2_{мин}} = 12$. The presented value of the signal/noise ratio was obtained for the incoherent reception of an elementary signal, in which regard the a priori probabilities of transmission of the pulse and pause are the same. In the system for the study of the multipath propagation the a priori probabilities of the pulse and pause are not equal, but in work [3] it is shown that the consideration of this inequality virtually does not change the results obtained with the assumption of equality of a priori probabilities.

The synchronous accumulation of a signal at the same distance from the sweep origin leads to an increase in the linear density of the signal blips on the photo film relative to the noise blips distributed over the entire film area. This process is equivalent to the synchronous post-detector integration which, with linear detection, leads to an increase in the signal/noise ratio (for power) of n times and, with quadratic detection, of $\sqrt{n}$ times. Here, n is the number of pulses being integrated. Thus, considering that during a session we integrate 1000 pulses, in the worse case for an error probability of 5% the minimum value of $\sqrt{h^2}$ becomes equal to 2. The estimate of the system's noise stability which was given above is important to determine the time of existence of the attenuated waves which have been repeatedly reflected from the ionosphere and whose power is comparable with the power of the noise.

A procedure for measurements and data processing. Several general methods exist for the study of multipath propagation on long communication lines which operate through reflection from regular formations in the ionosphere. The short-pulse method was employed on an experimental Moscow-Alma-Ata route with a length of 3100 km. It is obvious that with this method the pulse repetition frequency should be greater than the maximum possible on this delay route. With multipath propagation the received signal consists of a number of components which cover the path from transmitter

to receiver by various modes. The possible modes for the propagation of a signal on our route are shown in Fig. 1a. Calculations which were accomplished in approximating geometric objects show that the beams which arrive successively after the first one can be delayed for a time of from 1 to 10 milliseconds.

The duration of pulses sent by a Moscow transmitter equals 300 μs. The repetition frequency equals 80 ms which, as is evident, greatly exceeds the maximum possible on our delay route.

Measurements were conducted from September through the end of November 1968. Recording of the pulse signal (call signs) of the Moscow transmitter on motion picture film was conducted simultaneously with the reception by hearing and with the visual observation of a check oscillograph. The signal recording interval was approximately equal to two minutes with a preliminary 10-second calibration recording. Altogether, 132 recording sessions were obtained.

The time of existence of a beam which is delayed relative to the first by an amount which is determined from the distance between the line on the record was calculated from each recording session. The values which were obtained were divided over the entire recording session interval to obtain the relative time of existence of the delaying beam. The goal of further analysis was the disclosure of the dependence of parameters of multipath propagation on the ratio of the operating frequency to the MPCh for the F2 layer. Therefore, all data were divided into 8 groups. The first group included the data obtained at frequencies which, at the moment of measurement, comprised from 20 to 29% of the MPCh for the F2 layer; the second group - data obtained at frequencies which, at the moment of measurement, comprised from 30 to 39% of the MPCh for the F2 layer, etc. The MPCh for the F2 layer was calculated from data of the vertical sounding ionospheric station located approximately in the middle of the Moscow - Alma-Ata route (city of Kazalinsk). Within each group, the relative time of existence

was summed and normalized to the largest value. The results of probability distribution for the existence of a beam which is delayed relative to the first by a certain value which were obtained for all 8 groups are shown in the form of a histogram in Fig. 3.

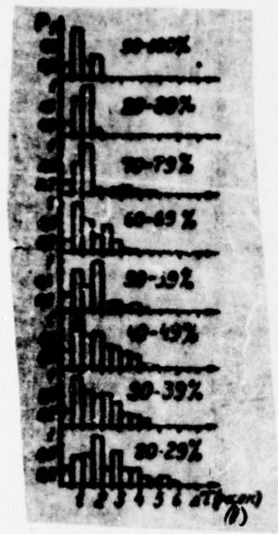

Fig. 3. Distribution of the existence probability of a beam which is delayed relative to the first by a certain value.
KEY: (1) ms.

The maximum delay time depending on the ratio F_p/MPChF2·100% was determined from these histograms for a certain level of existence probability PM (where M = 0.7, 0.5, 0.2). The values which were obtained are plotted in Fig. 4 in the form of points. The straight lines in the figures were drawn arbitrarily since the statistical data are insufficient for the precise determination of the mean value of maximum delay time.

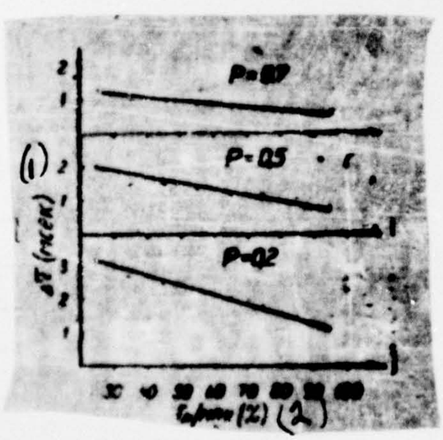

Fig. 4. Maximum delay time of a signal as a function of the ratio of operating frequency to MPCh.
KEY: (1) ms; (2) MPCh.

Discussion of results. The number of beams which arrive by various modes increases with a decrease in the ratio of the operating frequency to MPCh. If the number of beams equals 4 for the ratio F_p/MPChF2·100% = 90 - 100%, then for the ratio F_p/MPChF2× ×100% = 20-29% the number of beams equals 12. The maximum delay time which could be recorded and processed equals approximately 6 ms.

Most probable (PM = 0.6-1) are delays which lie within a range of from 0.5 to 2 ms. In this regard, it is evident that distribution of such delays does not depend on the ratio F_p/MPChF2. Approximate calculations showed that beams with such a delay can undergo two or three reflections from the E or $E_{спор}$ layer. Analysis of the dependence of the multipath propagation parameters on the ratio F_p/MPChE was not conducted because of the absence of data on critical frequencies of the E layer during the period of measurement. However, the dependence of the maximum delay time on the ratio F_p/MPChF2 is clearly manifested for levels of probability below 0.6; here, the greater the maximum delay time for a given ratio F_p/MPChF2, the less it is probable.

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